

Effects of Near Field Pyroshock on the Performance of a Nitramine Nitrocellulose Propellant

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Abstract

The overall purpose of this study is to investigate the effects of a pyroshock environment on the performance characteristics of a propellant used in pyrotechnic devices such as guillotine cutters. Near field pyroshock which is defined by acceleration amplitudes in excess of 10,000g at a frequency of greater than 10,000 Hz is a highly transient environment that has a known potential to cause failure in both structural and electronic components. A heritage pressure cartridge assembly which uses a nitramine nitrocellulose propellant with a known performance baseline will be exposed to a near field pyroshock event. The pressure cartridge will then be fired in an ambient closed bomb firing to collect pressure time history. The two performance characteristics that will be evaluated are the pressure amplitude and time to peak pressure. This data will be compared to the base-lined ambient closed bomb data to evaluate the effects of the shock on the performance of the propellant. It is expected that the pyroshock environment will cause brittle failures of the propellant increasing the surface area of said propellant. This increase of surface area should result in increased combustion rate which should show as an increased pressure peak and decreased time to peak pressure in the pressure time data.

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Future manned space vehicle configurations have evolved into capsule style crewed modules similar to that of the earlier manned space vehicles such as the Apollo spacecraft command module. This change to the capsule and stack configuration has also driven increases in the shock environments that critical pyrotechnic systems will see during flight. In order for pyrotechnic components to be qualified and accepted for flight, destructive lot testing includes simulated maximum expected performance environments with additional margin. This research was performed to investigate the effects of a simulated near field pyroshock environment on the performance characteristics of a nitramine nitrocellulose propellant loaded into a heritage pressure cartridge device.

As many pyrotechnic devices and propellants see reuse from program to program a couple of questions arise concerning the effects of near field pyroshock. Does a near field pyroshock event cause brittle failure of the propellant grain? If the grain fractures or cracks does the increased surface area increase the burn rate of the propellant? These questions need to be addressed as any potential increase in performance of the propellant would need to be qualitatively understood in order to feed back into design parameters. The objective of this paper was to evaluate any change of performance of a heritage pressure cartridge assembly that was subjected to a near field pyroshock environment.

Test Article

The cartridge assemblies used for this study were from a heritage pyrotechnically actuated piston device. The cartridge is loaded with a nitramine nitrocellulose propellant and is initiated with a NASA Standard Initiator (NSI). Use of this type of pyrotechnic cartridge is very common to current and future pyrotechnic devices including guillotine cutters and gas generators. The propellant combustion provides the required gas pressure and volume that is used to perform mechanical work such as moving a piston. The performance of this propellant for this cartridge has been well established over many different assembly flight lots and many decades. The two performance characteristics of the propellant in question for this study are peak pressure and time to peak pressure from first indication of pressure. These are used as a pass fail criterion for flight lot acceptance of these cartridges. This data is acquired from functioning of the cartridges within a closed bomb which measures said criterion. Three of these cartridges will be subjected to a near field pyroshock and then functioned within a closed bomb to measure their pressure time history. The pressure peak and time to peak pressure will be compared against the lot performance as well as a reference cartridge. A faster and higher peak pressure in the shocked cartridges will be indicative of a change to the propellant performance.

Pyroshock Environments

Pyroshock is “the response of a structure to high-frequency (thousands of hertz) high-magnitude stress waves that propagate throughout the structure as a results of an explosive device.” [1] Pyroshock is separated into the following three regions, near field, mid field, and far field. These regions are defined differently throughout government and industry and Table 1 details the various definitions. This environment is highly transient with large accelerations over a minimal amount of time, on the order of tens of milliseconds. The acceleration and frequency magnitudes decrease respectively with the order of the listed regions with near field being the highest and far field being the lowest.

The most severe of the pyroshock regions is in the near field. The near field pyroshock environment is defined as, "Near-field is a location on the structure that is sufficiently close to the pyrotechnic source for the response to be dominated by the direct compressive wave propagation from the source"[2] The source of a near field pyroshock environment is typically in the functioning of a pyrotechnic devices such as stage or fairing separation systems and other detonable pyrotechnic devices. These devices tend to be within close proximity to each other and can be found to be separated by as little as one to six inches.

Effects of Near Field Pyroshock Environments

Almost all pyrotechnic devices are a source for creating a pyroshock environment. The severity of the environment is dependent on the energy and the proximity of to the shock. The transmitted shock will be higher for detonable devices such as frangible bolts and lower for other deflagrating devices such as delay charges or smaller cutters. The produced shockwave will be propagated from the source device along any structure into adjacent devices. As previously defined, this near field pyroshock will propagate as a compressive shock wave to nearby devices. In this case it not the compressive shockwave that is suspect for causing damage to the propellant grain. Since the propellant is loosely loaded inside the cartridge housing it can be reasoned that a minimal amount of the compressive shock will actually transmit directly into the grain. This is because it is not in intimate contact with the housing walls. Rather, the shockwave will cause highly transient and large velocity changes at the cartridge interface. It is known that materials will transition from ductile to brittle failure because of the increased strain rate. It is thought that these high velocity changes are responsible for fracturing of the propellant grain as it impacts the housing walls and other grains. This impact is severe enough that it provides the potential brittle failure mechanism. This will lead to fractures or cracks within the grain and an increased surface area.

Effects of Impact on Propellant

Previous work on the effects of impact on gun propellant has been performed by the Ballistic Research Laboratory.[3] This report details the attempt to quantify the changes to performance of two gun propellants after impact. The two gun propellants studied were M30 and JA2 and were impacted via drop weight mechanical testers and gas gun impact testing. The impacted propellant was functioned in closed bomb firings after impact. Several plots showing the surface area ratio and the fraction of grain burned were produced. Some of those plots are included in this report as Figure 3. They show the results of the closed bomb firings on a range of damaged propellant. The severity of damage ranges from undamaged propellant grain to a severe brittle fracture. The amount of surface area available for combustion increases with increased severity of damage, caused by increasing fractures. The highest severity of fracture, fracture into small pieces, has an initial area ratio of approximately eight compared to the lowest severity of fracture, internal fracture, with a ratio of one. Their results have been summarized in the report as, "Finer fractured particles produce higher initial peaks and longer sustained burning at high surface area ratios." [3]

A similar behavior is expected of the propellant grains subjected to near field pyroshock. The impacting grains should exhibit some level of fracturing effectively increasing the available surface area. "The burning rate will increase as the burning surface area increases. Small grains will burn faster than large grains due to their greater surface area per gram." [4]. This should result in higher initial pressure peaks and faster combustion rates in the closed bomb firings.

Although this is thought to be the primary factor in increased performance another potential factor exists in the mechanical working of the propellant grain.

Mechanically Enhanced Reactivity

An additional factor that can cause increased propellant performance is the effects of mechanically working the propellant. The strain rate of the material due to the pyroshock can still be insufficient enough to reach the ductile to brittle transformation point. In this case, it is still possible that the propellant will deform plastically. Yielding or plastic deformation of the material would be analogous to a mechanical process of milling or rolling. Several experiments detailed in reference five looked at the heat of solution from a calorimeter on an unrolled and rolled copper oxide dissolved in hydrogen chloride, x-ray diffraction of lattice faults in milled red lead oxide, and dry grinding of sulfur and potassium perchlorate. The effects of mechanical working on solid-solid reactions was summarized as, "milling enhances reactivity not so much by particle size reduction as by lattice deformation, though the two may be unavoidably linked." [5] The results showed the following: rolled copper oxide produced more energy than an unrolled copper oxide, yellow lead oxide converted to red oxide via the milling process, and ground sulfur potassium perchlorate had reduced ignition temperatures. The near field pyroshock may not induce fractures to the propellant grain but may still show increased performance by lattice deformation. There exists two separate mechanisms that may ultimately cause increased performance.

Testing

The three cartridges were installed into a pyroshock fixture that comprises of a test article shelf and a resonant plate. A PrimaCord charge is placed onto the resonant plate and detonated by a shock tube detonator. Acceleration time history is measured via shock accelerometers and laser vibrometers that are positioned along the PCA normal (Z) and in plane directions (X and Y). A high speed data acquisition system and signal conditioning is required to measure acceleration time history. The acceleration time history is used as the input to the shock response spectrum (SRS) analysis to generate the SRS plot shown in Figure 1. The shock response spectrum analysis is a model built upon a single degree of freedom system with infinite natural frequencies. The peak acceleration response for a specific natural frequency based off of a frequency range is calculated for both the positive and negative directions in the acceleration time history. Typical natural frequencies are spaced as a proportional bandwidth split and for this test were spaced on a 1/6 octave from the lower frequency to the upper limit.

The cartridges were subjected to shock in both the positive and negative directions for three mutually orthogonal axes. The levels attained are in the near field pyroshock region as defined previously. Only the laser vibrometer shock response spectrum is shown for brevity. Closed bomb firings were then subsequently performed to evaluate the performance of the cartridge propellant. A closed bomb is a constant volume bomb designed to measure a pressure trace. It is ported to accept the output end of the cartridge and primary and secondary pressure transducers. The pressure transducers used are high impedance charge mode piezo-electrics that have been designed specifically for ballistics measurements. Closed bomb firings are performed per the following procedure: The cartridge and pressure transducers are installed into the closed bomb. A firing line which is connected to an initiator firing unit is installed onto the NSI of the cartridge. The firing unit is fired providing the minimum energy and power required to initiate the NSI's propellant. The deflagration of the propellant initiates the propellant within the

cartridge. The propellant combustion creates high temperature gas which is contained within the closed bomb and measured with pressure transducers via a digital oscilloscope. A reference cartridge of the same lot that was not subjected to pyroshock was also functioned for comparison purposes. The pressure peaks and time to peak pressure from first indication of pressure are detailed in Table 2, only the primary pressure transducer results are shown for brevity. The pressure time data has been normalized about the reference pressure cartridge firings to better highlight any differences. The pressure time traces as well as the lot acceptance criteria are shown in Figure 2.

Results/Conclusion

The resultant data from the closed bomb firings did not provide sufficient evidence to support the theorized increased performance of a nitramine nitrocellulose propellant subjected to pyroshock. It was theorized that the pyroshock environment would cause brittle failure of the propellant grain leading to an increased amount of surface area available for combustion. This increased combustion propagation would coincide with a higher peak pressure and a faster pressure rise to its peak value. The data did not show any clear indication of a change in the propellant performance. Given the relatively small sample size it is reasoned that the peak pressures and time to peak pressure remained within the normal distribution for this specific lot of cartridges. The variability from each closed bomb firing is minimal and well within the pass fail region. Only one of the cartridges exhibited a higher peak and time to peak than the reference cartridge. While potentially an indication of higher performance as stated previous this change is minimal and cannot be considered indicative of a change to the propellant. Future work should include a greater sample size and look at multiple environments including both hot and cold thermal environments. Different types of propellants or explosives used within heritage pyrotechnic systems should also be tested to evaluate susceptibility to shock.

References

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Tables

Table 1: Pyroshock Region Definitions [2]

Document	Region	Acceleration Amplitude (g)	Frequency (Hz)	Distance from Source	
				Intense Source	Mild Source
NASA STD 7003	Near-field	>5000	>100 k	<6 in.	<1 in.
	Mid-field	1000–5000	>10 k	6–24 in.	1–6 in.
	Far-field	<1000	<10 k	>24 in.	>6 in.
IEST-RP-DTE032 and MIL-STD-810G, Method 517	Near-field	>10,000	≥10 k		
	Mid-field	<10,000	3 k–10 k		
	Far-field	<1000	≤3 k		

Table 2: Closed Bomb Firing Data

Normalized Time and Pressure Data		
Reference	Peak Pressure	Time To Peak from FIP
	P	T
Cartridge A	Peak Pressure	Time To Peak from FIP
	0.9874P	1.0816T
Cartridge B	Peak Pressure	Time To Peak from FIP
	1.0208P	0.7960T
Cartridge C	Peak Pressure	Time To Peak from FIP
	0.9895P	1.1224T

Note: FIP = First Indication of Pressure

Figures

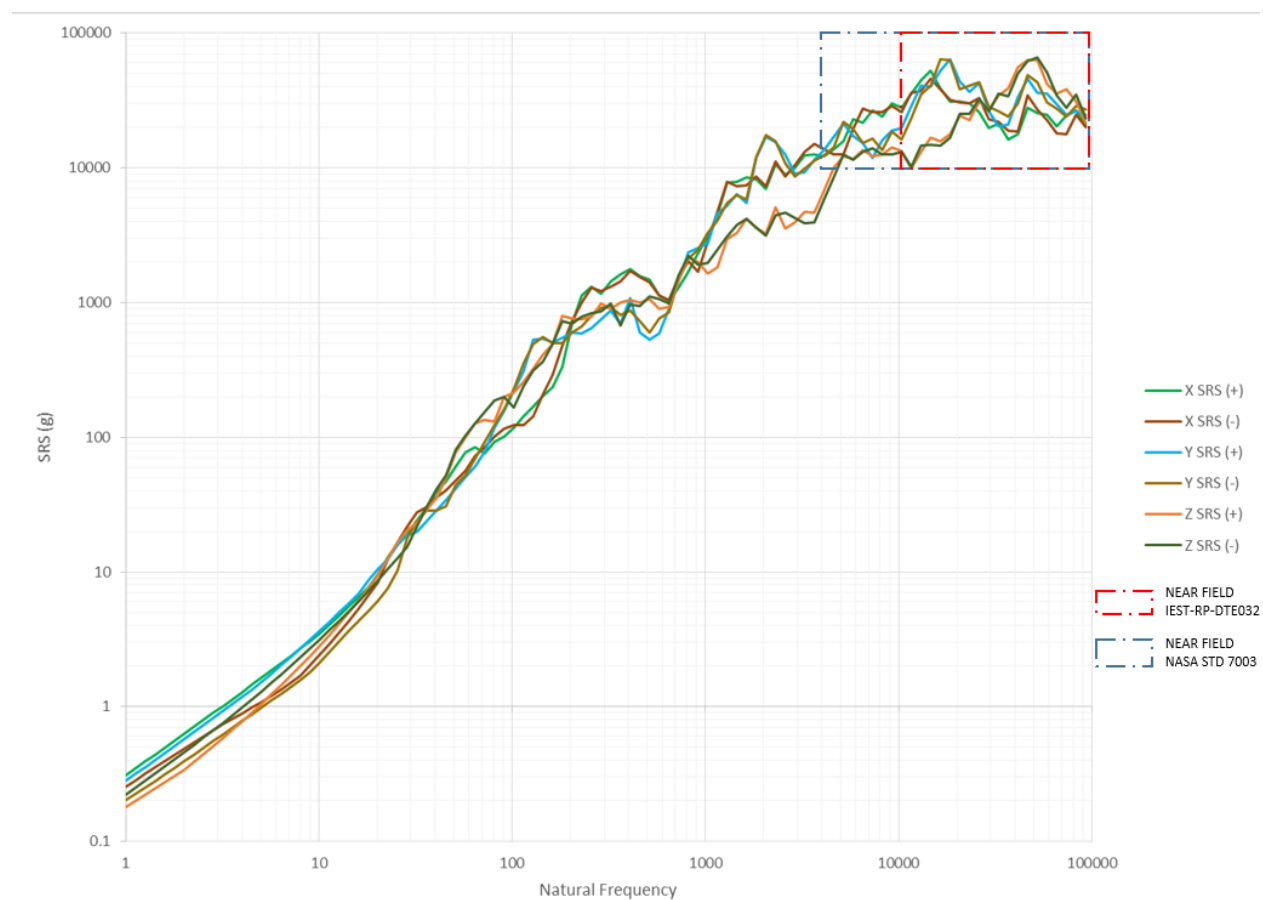


Figure 1: Pyroshock Simulation Shock Response Spectrum for Cartridge A, B, & C.

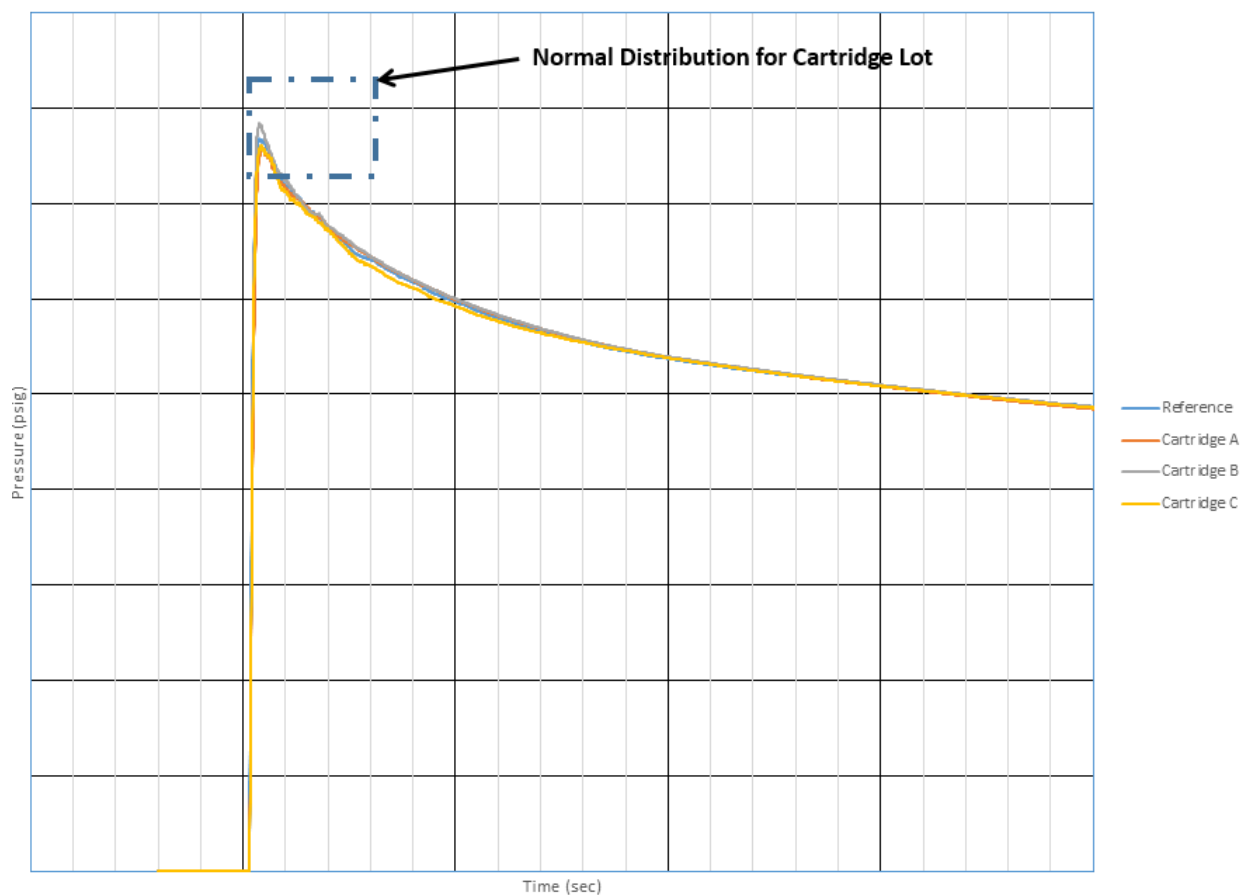


Figure 2: Primary PT Pressure Time History for Reference Cartridge and Cartridge A, B, & C.

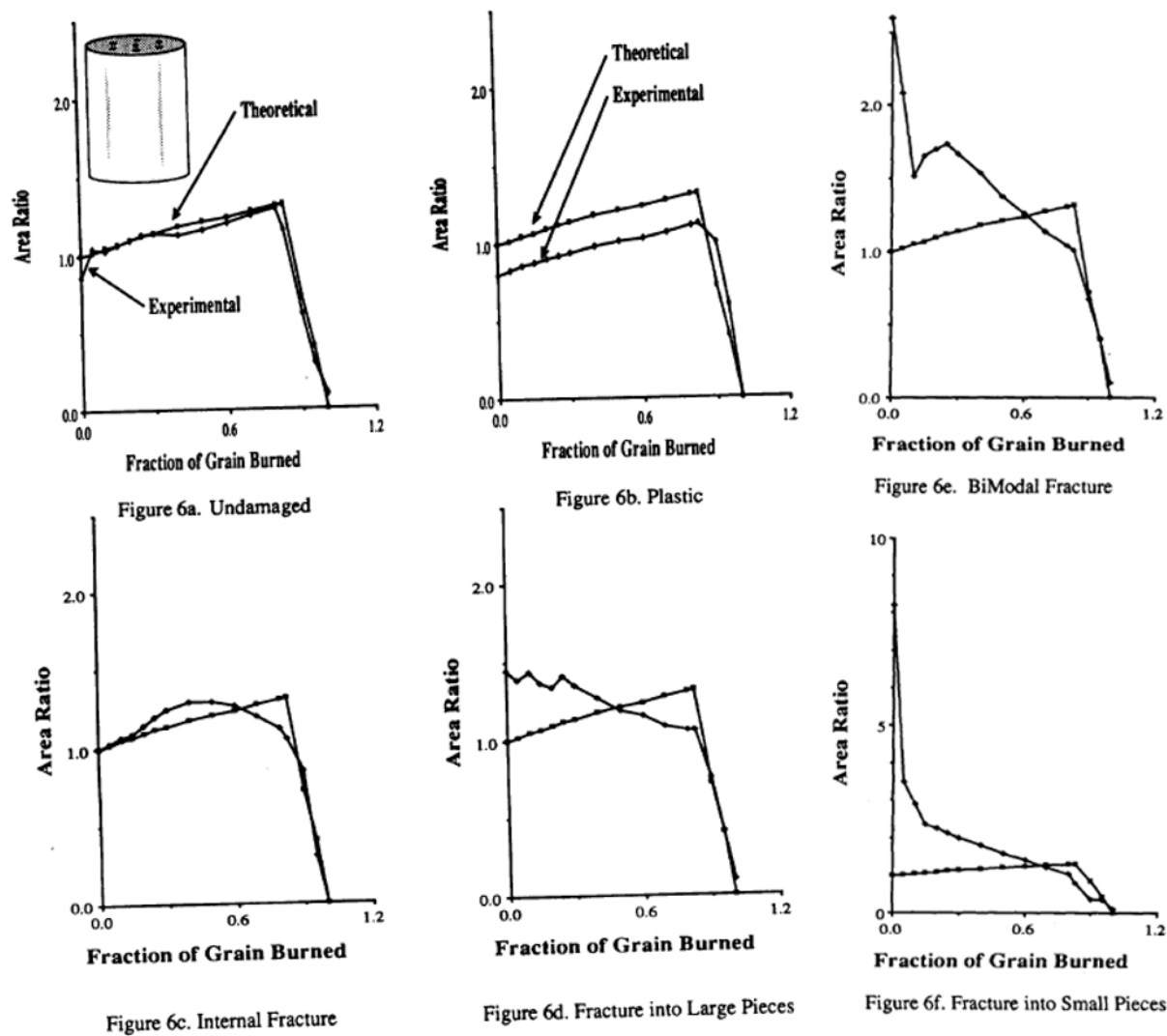


Figure 2: Area Ratio and Fraction of Grain Burned for Different Fractured Propellant Grain [3]